5. FIELD MEASUREMENTS

5.1 Introduction

As noted previously, atmospheric water is crucial to the Earth's heat balance. In the absence of any greenhouse gases or clouds, the mean temperature at the Earth's surface would be ~ -18°C, substantially lower than the actual value of ~ 15°C; water vapor is, in fact, the dominant contributor to the Earth's greenhouse effect. On the other hand, if convection did not carry most of the sensible and latent heat lost by the Earth's surface above the bulk of the water vapor, which is found in the lowest ~ 2 km of the atmosphere, to much higher altitudes, and if large-scale meridional circulation did not carry heat from the moist tropics to the drier temperature latitudes, the Earth would experience a much stronger greenhouse effect due to the trapping of heat by the low-level moisture.

To increase our understanding of the greenhouse effect, a series of preliminary data flights of the NASA WB-57A were made in 1994 using the ARES MWIR Spectrometer to take data useful in determining the water content of the atmosphere for altitudes ranging from about 6 to 18 km. These flights are listed in Table 3. They were flown on missions over the Cloud And Radiation Test-Bed (CART) site in Lamont, OK, a facility of the Atmospheric Radiation Measurement (ARM) program of the US Department of Energy (DOE). Data derived only from the 31 May and 14 December flights are discussed herein.

Table 3. ARES Flight

Date	Туре	Altitude Range
23 May 1994	Solar Test Collect	60 to 30 kft
31 May 1994	Solar Nominal Collect	60 to 20 kft
25 August 1994	Lunar Collect	60 to 20 kft
14 December 1994	Lunar Collect	61 to 20 kft

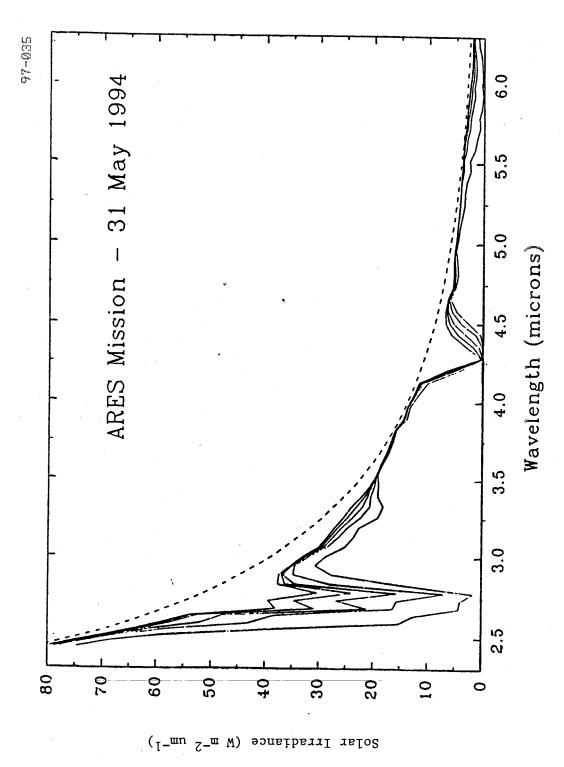
5.2 ARES Data Analysis

On 31 May 1994, the ARES spectrophotometric instrumentation, on board the WB-57F aircraft, was flown on a preliminary mission over the CART site. The instrumentation was use to measure the attenuated solar spectral in the wavelength range from ~ 2.3 to ~ 6.3 µm, for altitudes ranging from ~ 6 to ~ 18 km in intervals of ~ 1.5 km.

Results for attenuated solar spectra are shown in Figure 5. The solid curves are for altitudes of 20, 30, 40, 50, and 60 kft (lowest to highest curves, respectively). The dashed curve is a 5900 K blackbody spectrum, which approximates the unattenuated solar spectrum above the Earth's atmosphere, shown for comparison. The absorption between ~ 5.8 to $\sim 6.2 \,\mu m$, which is due to water vapor, was used to infer the column density of water vapor above the aircraft at each altitude. (The absorption near 3.4 μm is due to methane and may be used in future analyses to infer the column density of methane above the aircraft.)

By use of a code such as MODTRAN,^[8] that can model atmospheric absorption as a function of infrared wavelength, atmospheric temperature profile, and distribution of the absorber in the overlying atmosphere, the column density of the absorber above the aircraft can be deduced. A preliminary analysis of this type has been carried out to infer the column density of water vapor at each of the nine altitudes sampled during the mission. By differencing the column densities obtained at adjacent altitudes, the local volume density of water vapor can be inferred. In combination with measurements of the ambient pressure and temperature, the volume density can, in turn, be converted into a measure of quantities of interest, such as concentration and dew point. A sample of the results of this analysis is displayed in Figure 6. The open squares are preliminary estimates of water vapor volume density at altitude increments of 1 km.

The 31 May 1994 mission was coordinated with the launch of radiosondes from the CART site. The sondes, described in Section 4.2, are capable of measuring dew points to a nominal lower limit of -60°C (compared to a lower limit of -40°C for standard sondes). One sonde was launched approximately 90 minutes prior to the overflight of the aircraft, while the second was launched about 90 minutes after the overflight; both sondes remained within ~ 30 km of the site throughout the data collection phases of their flights. The volume densities of water vapor for altitudes up to 18 km above the site, as inferred from the sonde data, are also shown in Figure 6. The solid curve with



Attentuated Solar Spectral Irradiance for Various Altitudes Figure 5.

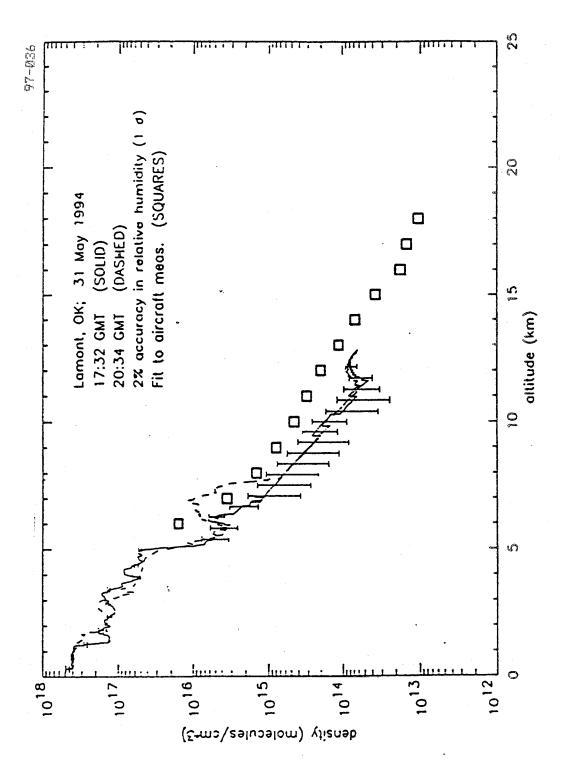


Figure 6. Estimates of Water Vapor vs. Altitude

vertical errors bar is for water vapor volume densities derived from data obtained with a radiosonde launched ~ 90 minutes prior to the overflight of the WB-57F aircraft. Each error bar corresponds to a nominal 2% absolute error in the measured relative humidity. The dashed error curve is for water vapor column densities derived from data obtained with a sonde launched ~90 minutes after the overflight of the aircraft. The uncertainties (not shown) are essentially the same as those for the earlier sonde.

A comparison of the water vapor densities inferred from the ARES data with those measured by the radiosondes indicates a satisfactory level of agreement. Note, in particular, that the water vapor density at ~7 km as inferred from the ARES data is bracketed by the two sonde measurements, indicating that the water vapor density at this altitude was steadily increasing with time during the course of the measurements. Additional data acquired by the sondes is described in Section 5.3.

The 31 May 1994 ARES measurements utilized a neutral density filter with an attenuation factor of 10^4 . This suggested the possibility that a much fainter astronomical source, such as the Moon, could be used as the background source against which infrared absorption by water is measured. Two additional preliminary missions on 25 August 1994 and 14 December 1994 demonstrated the feasibility of nocturnal observations by substituting the Moon for the Sun in this manner. On the latter flight, the ARES instrumentation also detected three bright stars, including α Orionis, with good signal-to-noise, suggesting the possibility that useful nocturnal data can be obtained even during the dark of the Moon.

Figures 7 and 8 are ARES data obtained by observations of the Moon during the mission on 14 December 1994. Figure 7 is the signal strength (apparent lunar brightness), in arbitrary units, as a function of aircraft altitude (1 kft \approx 0.3 km) at each of five infrared wavelengths within and adjacent to the water absorption band. Figure 8 is the signal strength, in arbitrary units, as a function of infrared wavelength, in the vicinity of the water absorption band at each of six aircraft altitudes.

5.3 Sonde Data Analysis

In conjunction with ARES measurements, four radiosondes were launched on 31 May 1994 from the CART site in Lamont, OK. The sondes were launched at 1130, 1432, 1732, and 2034

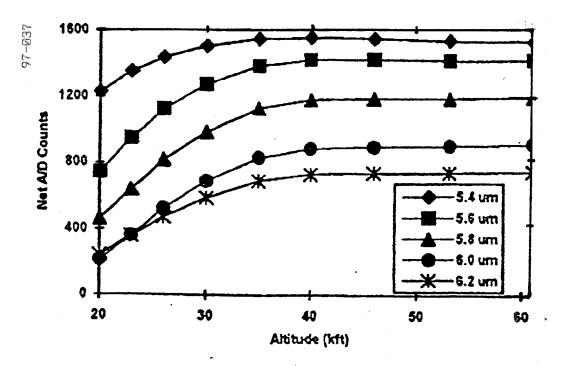


Figure 7. Signal Strength vs. Altitude Data from 14 December 1994 Mission

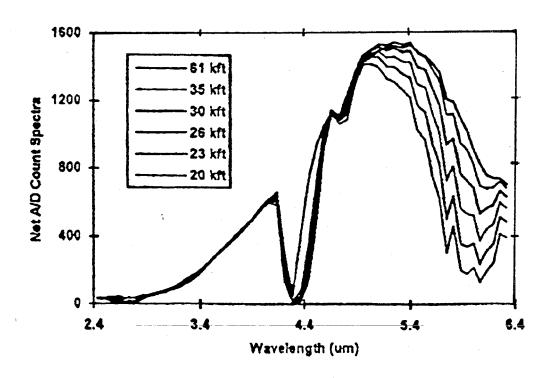


Figure 8. Lunar Signal vs. Wavelength Data from 14 December 1994 Mission

GMT. The ARES H₂O measurements were bracketed by the third and fourth sonde launches. The FIRST ARES measurement began at 1747 GMT and the last at 1909 GMT.

Figures 9-12 show the altitudes as functions of latitude and longitude for the 1732 GMT and 2034 GMT sondes. The paths of the two sondes are quite close and differ by at most approximately 0.01° earth center angle, which corresponds to a distance of approximately 1 km.

Figures 13-24 summarize the H_2O measurements results for the four radiosonde launches. It should be noted that the "dry bulb temperature" is the actual ambient temperature, whereas the "dew point" temperature is a derived value plotted for comparison only. On the H_2O density plots, data corresponding to ambient temperatures less than -60°C are not included. Uncertainty bars corresponding to the $\pm 2\%$ of full scale accuracy in relative humidity are also plotted. These error bars represent 1σ errors; therefore, they should be considered very conservative.

The relative humidity altitude profiles are fairly typical with moderate and highly variable relative humidity from 0 to 5 km altitude, a quiescent region of low relative humidity above 5 km, and an increase in relative humidity near the tropopause (12-18 km). The relative humidities as a function of altitude for the 1732 and 2034 GMT sonde flights are also quite close with the exception of a feature at 7 km altitude. This may represent either spatial or temporal variability in the local water vapor density.

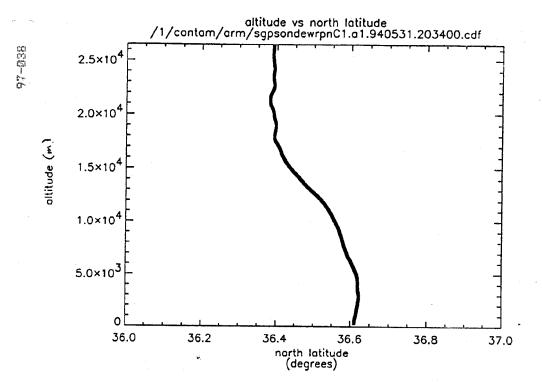


Figure 9. Altitude vs. Latitude for the 1732 GMT Sonde

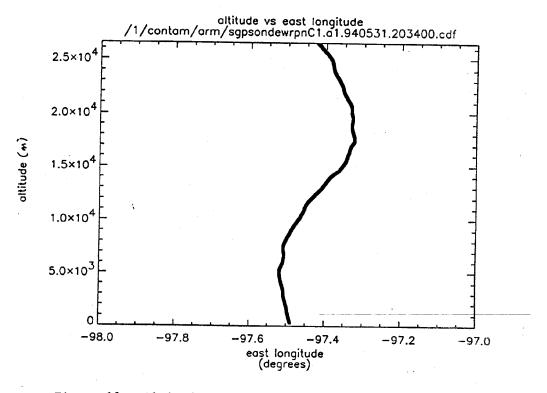


Figure 10. Altitude vs. Longitude for the 1732 GMT Sonde

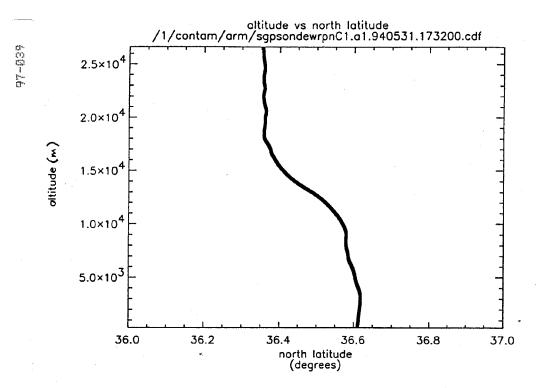


Figure 11. Altitude vs. Latitude for the 2034 GMT Sonde

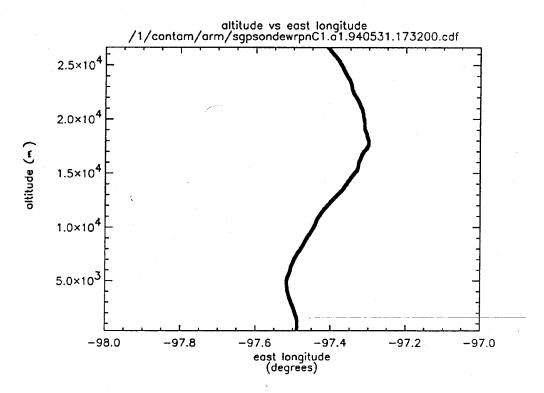
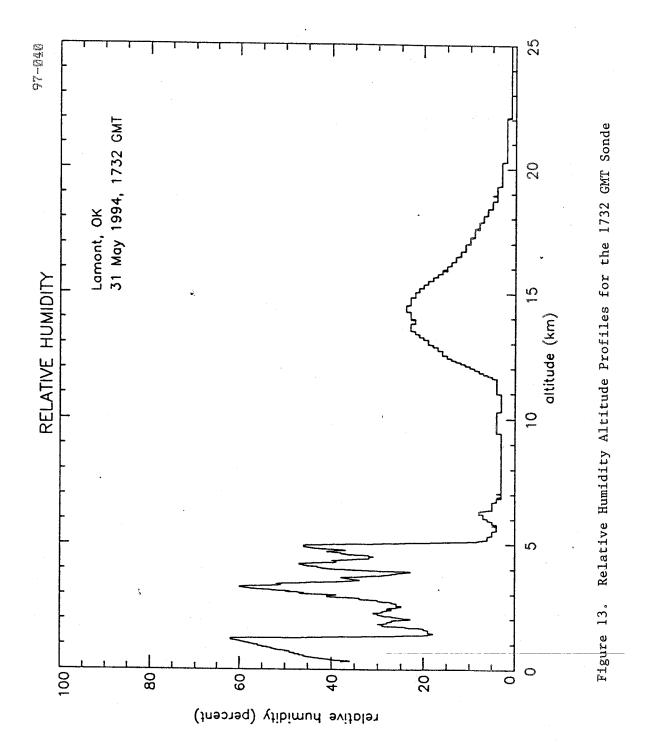


Figure 12. Altitude vs. Longitude for the 2034 GMT Sonde



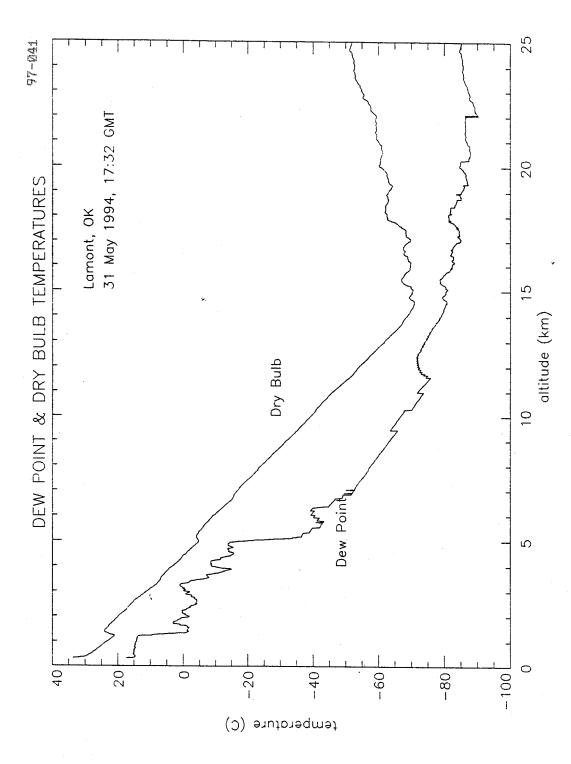
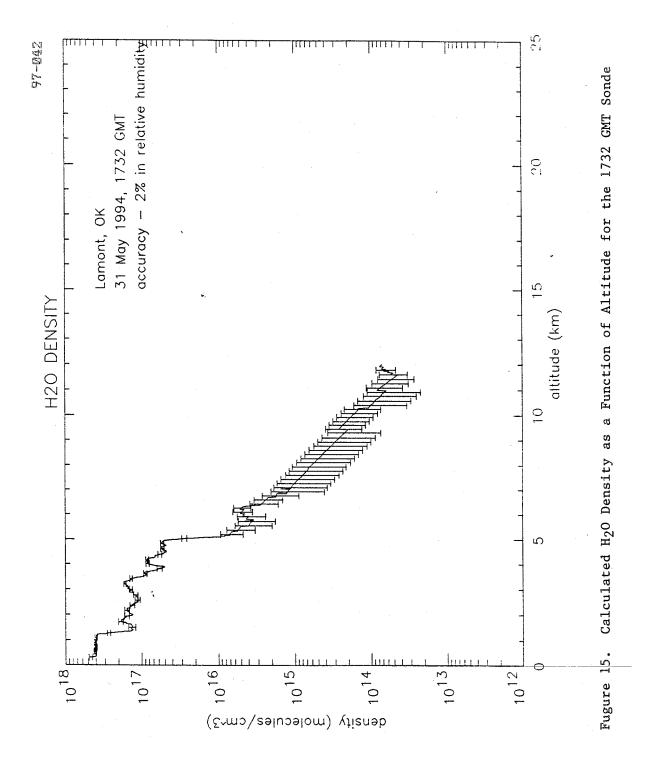
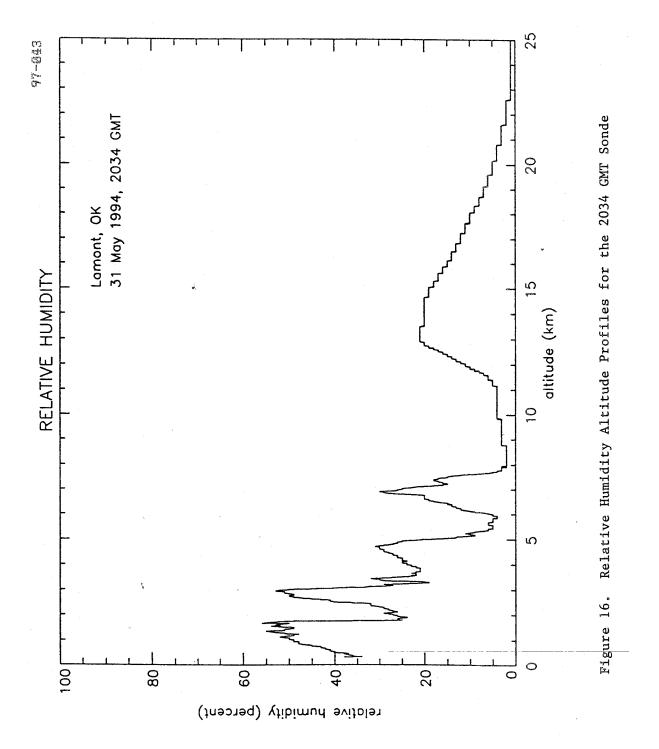
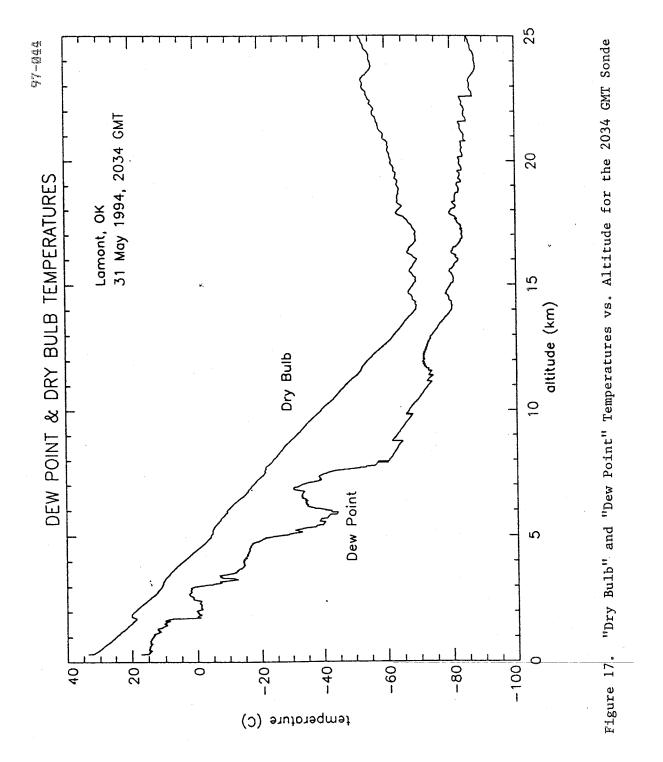
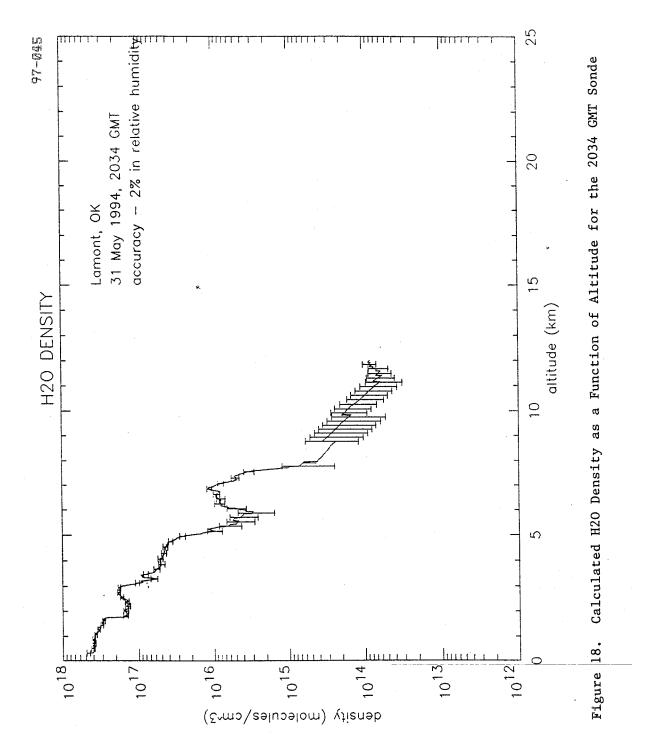


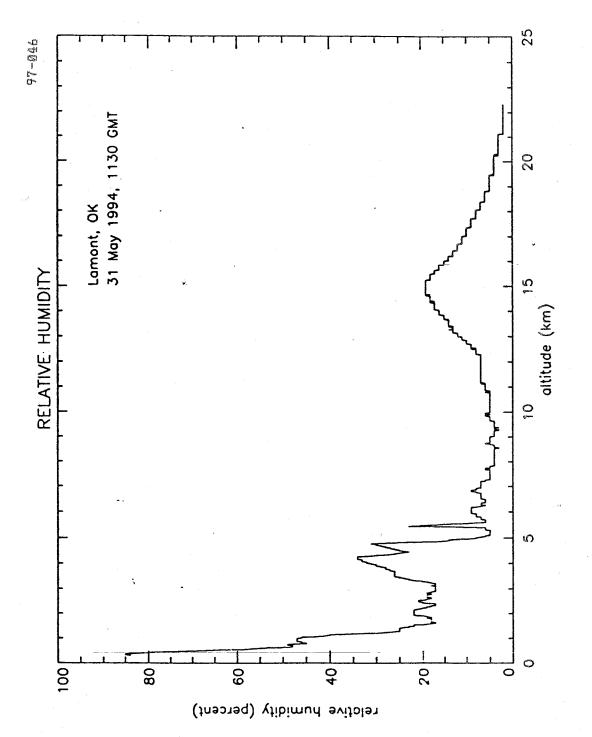
Figure 14. "Dry Bulb" and "Dew Point" Temperatures vs. Altitude for the 1732 GMT Sonde











Relative Humidity Altitude Profiles for the 1130 GMT Sonde Figure 19.

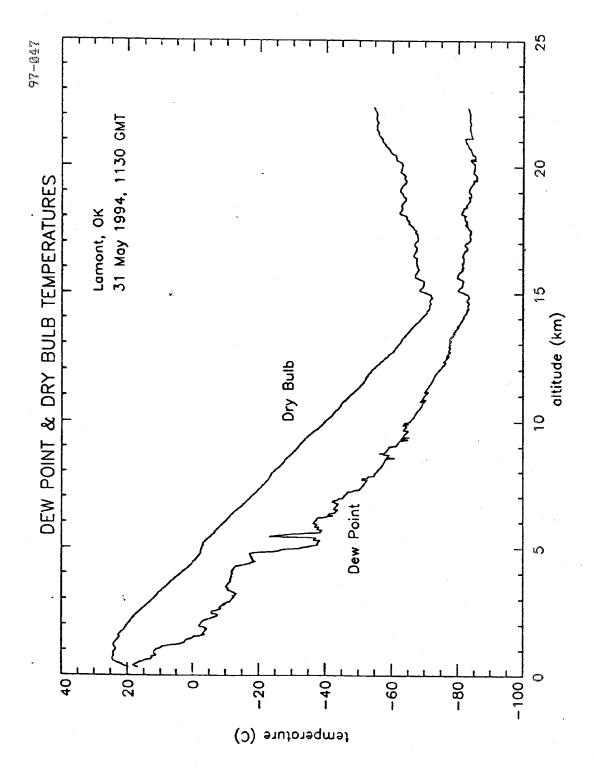
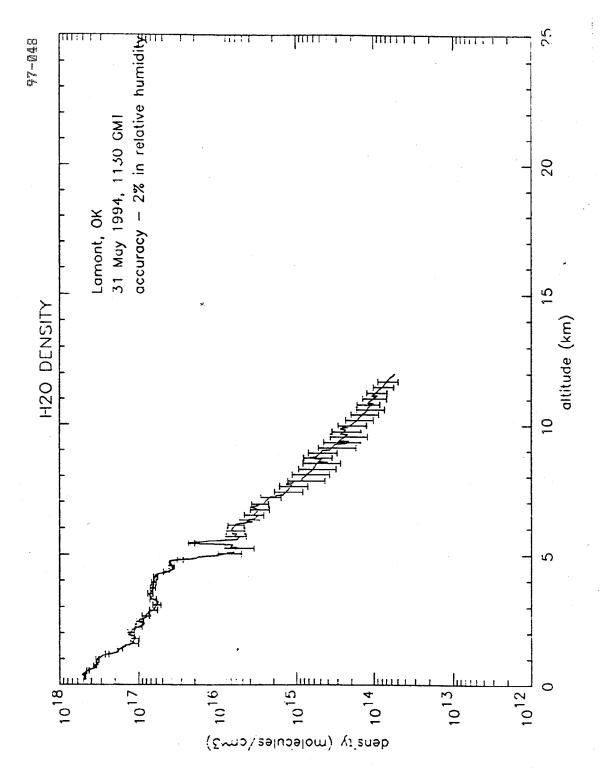


Figure 20. "Dry Bulb" and "Dew Point" Temperatures vs. Altitude for the 1130 GMT Sonde



Calculated $\mathrm{H}_2\mathrm{O}$ Density as Functional of Altitude for the 1130 GMT Sonde Figure 21.

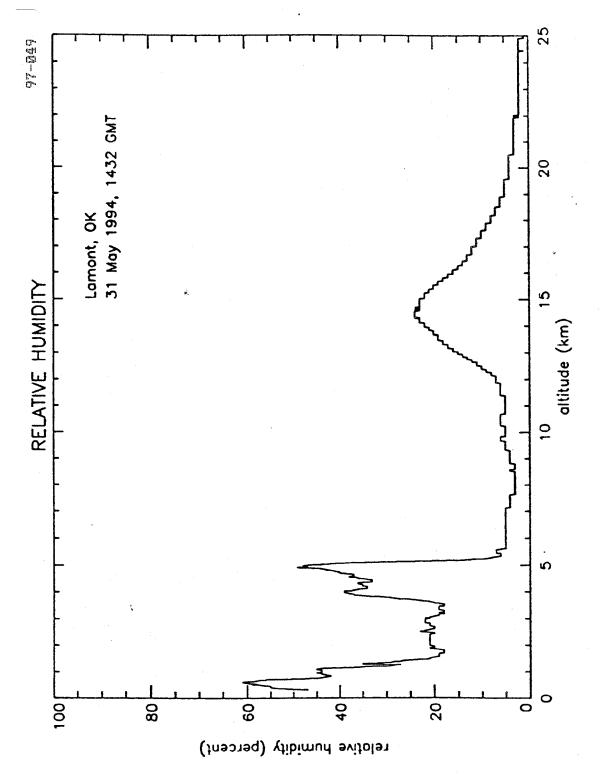


Figure 22. Relative Humidity Altitude Profiles for the 1432 GMT Sonde

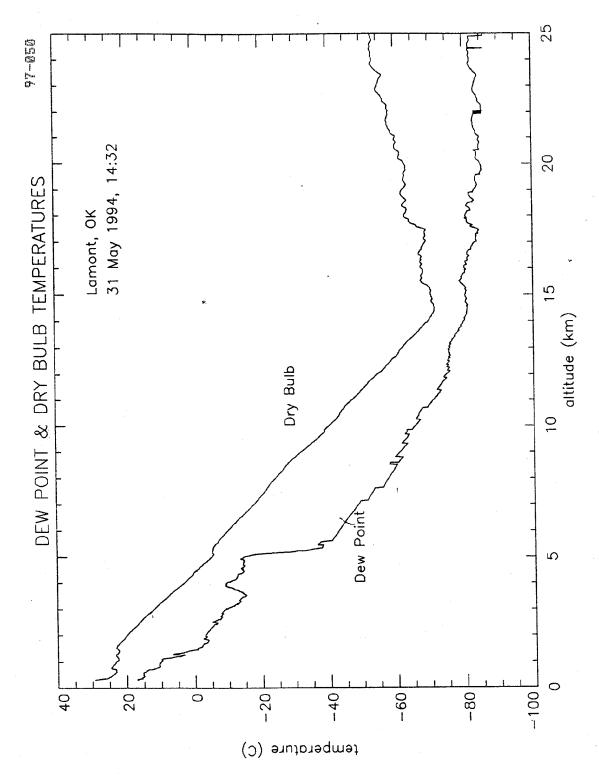
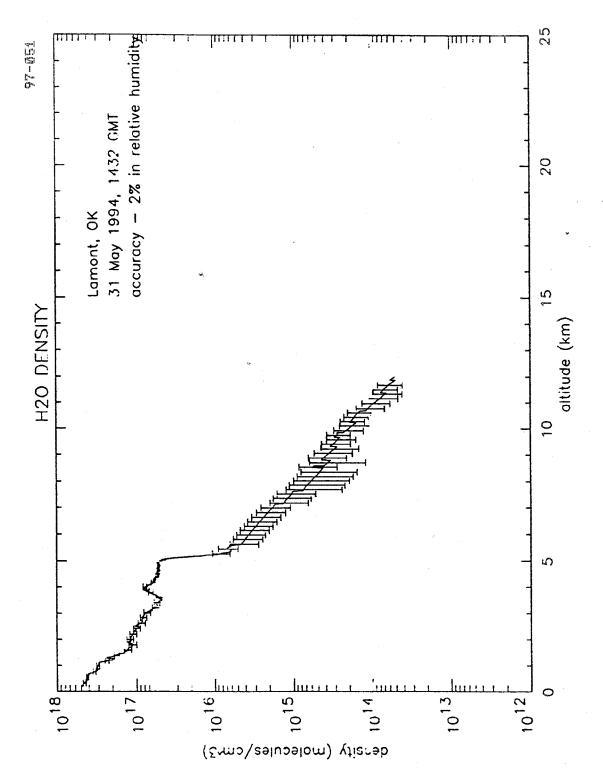


Figure 23. "Dry Bulb" and "Dew Point" Temperature vs. Altitude for the 1432 GMT Sonde



Calculated $\mathrm{H}_2\mathrm{O}$ Density as a Function of Altitude for the 1432 GMT Sonde Figure 24.